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14. ABSTRACT

This is the final report for Phase II of a three phase project. In this three phase project, we are integrating inexpensive, easily deployable magnetic measurement systems into small autonomous underwater vehicles (AUVs). These AUVs are being trained to work together to assess the magnetic signature of a forward deployed ship or submarine. This assessment is important to establish a vehicle's stealth condition relative to potential threats. Navy vessels, including submarines, go through a procedure where their magnetic and acoustic signature is measured and modified to reduce detection. This operation is performed in US ports. Unfortunately, no procedure is available for measuring and modifying these signatures for forward deployed vessels. Ideally, this process should be done just before the vehicle goes into an operation in a hostile environment. We are developing multiple AUVs having magnetic sensors that travel in a formation under navy ships to assess that ship's magnetic signature in forward deployed areas. All vehicle testing is being performed at the Acoustic Research Detachment of the Carderock Division of the Naval Surface Warfare Center in Bayview, Idaho.

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Magnetic Signature Assessment System using Multiple Autonomous Underwater Vehicles (AUVs), Phase 2

Final Report
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ABSTRACT

This is the final report for Phase II of a three phase project. In this three phase project, we are integrating inexpensive, easily deployable magnetic measurement systems into small autonomous underwater vehicles (AUVs). These AUVs are being trained to work together to assess the magnetic signature of a forward deployed ship or submarine. This assessment is important to establish a vehicle's stealth condition relative to potential threats. Navy vessels, including submarines, go through a procedure where their magnetic and acoustic signature is measured and modified to reduce detection. This operation is performed in US ports. Unfortunately, no procedure is available for measuring and modifying these signatures for forward deployed vessels. Ideally, this process should be done just before the vehicle goes into an operation in a hostile environment. We are developing multiple AUVs having magnetic sensors that travel in a formation under navy ships to assess that ship's magnetic signature in forward deployed areas. All vehicle testing is being performed at the Acoustic Research Detachment of the Carderock Division of the Naval Surface Warfare Center in Bayview, Idaho.

LONG-TERM GOALS

The long-term goal of this project is to develop a portable assessment system to evaluate the magnetic (M) signature of forward deployed ships and submarines. Inexpensive, easily deployable small autonomous underwater vehicles (AUVs) will be equipped with magnetic measurement systems. These AUVs will then be trained to work together to assess the magnetic signature of a forward deployed ship or submarine.

OBJECTIVES

The major objective of this work is to develop the preliminary system requirements and design for a portable stealth assessment system. Magnetic and acoustic sensors will be identified for this assessment system but the major emphasis will be developing and testing the magnetic sensing capability of AUVs for such a system. These tests will include static tests where a sensor is positioned relative to a stationary barge that includes a calibrated magnetic signal so that the sensor can be evaluated independent of any interference from an AUV. One sensor will be used per AUV and tests similar to the static tests will be performed where the AUV will move underneath a moving boat having a magnetic source. In addition to the AUV magnetic sensor tests, the passive navigation system will also be deployed on the boat and the accuracy of this system tested with multiple AUVs. From these tests and computer simulations of multiple AUVs making measurements under realistic scenarios, the preliminary requirements and a design for a portable assessment system will be developed.

APPROACH

The development of a portable system for assessing the magnetic signature of a vehicle is dependent on (1) accurate measurement of the field and (2) accurate location of the position measurement relative to the vehicle. For a stationary range, these two problems are decoupled because the sensors can be accurately positioned relative to a fixed coordinate system and only the ship's location relative to this coordinate system is needed. With a portable system, the sensors will be mounted on AUVs so that the AUVs can be deployed and properly positioned in order to make the measurements. Unfortunately, the AUVs which are used to position the sensors have their own magnetic signatures that can interfere with the measurements being made to evaluate a ship's signature. This coupling of the measurement with the requirement for properly locating the sensor complicates the procedure for establishing a ship's signature.

A number of approaches are being evaluated to eliminate or minimize the influence of the AUV on its sensor measurements. We have mounted the sensor on the outside of the AUV. This will help to reduce the noise and will make it easier to isolate the AUV's electronics from the sensors. We are also identifying the source of noise problems and attempting to eliminate or compensate for the noise as much as possible. Because the acoustic modem is a source of magnetic noise when it operates, we plan to implement a passive navigation system where the modems do not need to ping to determine their positions while taking data. We have added an improved Inertial Navigation System (INS) to the AUV in order to provide accurate position estimates between navigational updates. Although the drive motor produces magnetic noise, we have found that a simple filter can be used to eliminate the magnetic noise from the motor.

The AUVs need to be able to navigate accurately underwater and to communicate with each other and an operator in order to position themselves to make the measurements needed to perform the signature assessment. The important position information needed to accurately assess the ship's signature is the position of the AUV relative to the ship when the data is logged. We plan to use a passive navigation system, as mentioned above, where transponders attached to the ship will broadcast to the AUVs. The AUVs will have clocks synchronized to the transponder clocks enabling them to triangulate their position relative to the ship. Initially, the AUVs will be deployed to a location where they will create a formation so that they can take the appropriate data for signature assessment when the ship passes over them. The logistics of deployment and recovery will also be considered in this work. The UI has extensive experience in the navigation, communication, and control of multiple vehicles that can collaborate to perform specific tasks.

WORK COMPLETED

Five AUVs used for experiments as described in [1] have been fully equipped with both an inertial measurement unit (IMU) and a magnetometer, see Figure 1. The acrylic hull of one of these AUVs has been replaced with a high strength composite hull that will allow the AUV to operate at depths up to 150 meters. In the near future and as time permits, all the other AUVs will have their hulls replaced with the new high strength hulls. An additional AUV having increased computational power and able to run Linux on-board has also been fabricated and bench tested. This AUV uses gumstix microcomputers with Linux so that standard software called MOOS can be used to operate the AUV. In addition, the gumstixs provide the ability to implement more computationally intensive Extended Kalman Filters (EKFs) and improve the accuracy of the on-board AUV navigation [2] and to compensate for magnetic disturbances [3]. This AUV is ready to be tested in Lake Pend Oreille. A fleet of these AUVs would be able to fully implement the magnetic signature mission in the ocean's deep water.

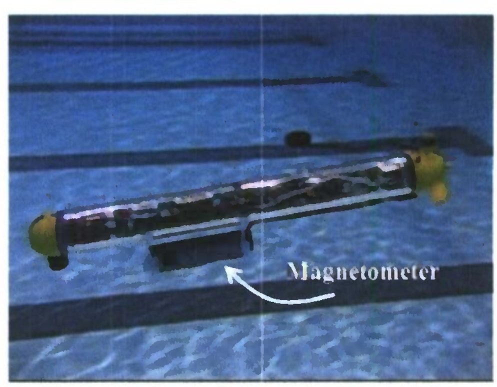

Figure 1. AUV equipped with Magnetometer.

Each fully equipped AUV has a six-channel data acquisition unit (DAU) and a six-axis IMU. Three channels of the data acquisition unit are dedicated to sample voltages corresponding to the three components of the magnetic field provided by the magnetic sensor. Digitization of the three signals occurs at a resolution of 16 bits and at a rate of 120k samples/channel. Each component of the magnetometer sensor is sampled at a rate of 12.5 kHz. The DAU is capable of storing 400 minutes (6.67hr) of magnetometer data at this rate. The six-axis IMU relies on solid state MEMS accelerometers and gyros. The accelerometers have a range of ±10g and an accuracy of 50μg. The gyros have a range of ±150°/sec and an accuracy of 0.0006°/sec. Experiments on AUVs in this configuration are presently being conducted at the Acoustic Research Detachment (ARD) in Bayview, Idaho.

In order to make accurate magnetic measurements relative to either a stationary or moving magnetic source, an independent position measuring system relative to ground coordinates is required. For this purpose, the Acoustic Research Detachment (ARD) has deployed a Topside Measurement System (TMS) in the deep waters of Lake Pend O'Reille away from sources that would pollute the magnetic field. Figure 2 shows the range layout for this system including the position of a known stationary magnetic source. The TMS is very versatile and can track multiple AUVs as well as provide navigation signals for them. The AUVs can use the TMS as a stationary long baseline (LBL) system for active navigation. In this mode, each AUV would actively ping the TMS transponders and they would respond allowing the AUVs to triangulate their position from the known positions of the TMS transponders. This navigation mode is called active LBL (Active-LBL) navigation. When the clocks of the AUVs are synchronized with the TMS clock, then the AUVs can use the timed pings from the TMS transponders to navigate passively without pinging. We refer to this navigation mode as synchronized LBL (Sync-LBL). The AUVs can use these modes of navigation (i.e. Active-LBL or

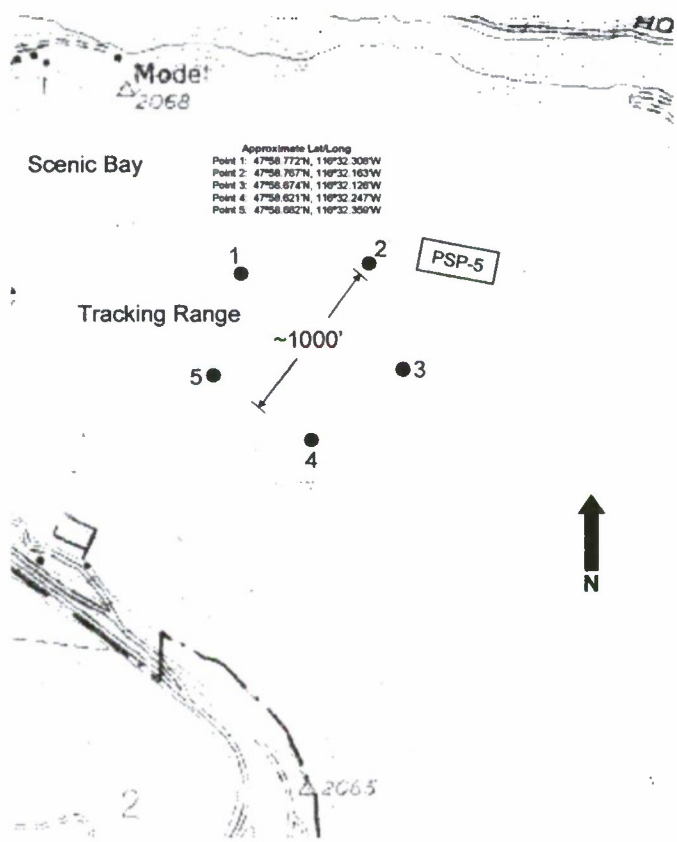

Figure 2. Range Layout for Topside Tracking System in Deep Water

Sync-LBL) for tests where the magnetic source is either stationary or moving. These navigation modes can be used for testing either one AUV or multiple AUVs.

A boat, as shown in Figure 3, is required for testing a moving source. In these tests a known magnetic source is attached to the bow of the boat. The operator of the boat uses information from a differential GPS system to drive the boat along a prescribed trajectory. The AUVs can then use different navigation methods, including the two previously mentioned ones that use the TMS transponders, to move beneath the boat and make the magnetic measurements of the moving source. In addition to using the TMS transponders for navigation, we have also implemented a navigation system consisting of two transponders located on the boat that ping at timed intervals. The AUV clocks are synchronized with the boat transponder's clock so the AUVs can navigate relative to the boat. This navigation method is referred to as the moving short baseline (MSBL) system. The boat shown in Figure 3 has transponders located at the end of the two outriggers so that the transponders are about 30 feet apart. Because only two transponders are being used on the ship, efforts have been completed to counter certain instabilities in position determination that can occur when acoustic ranging takes place with two transponders [4]. The navigation ping used for navigation also contains a WHOI Micro-Modem 13-bit Communications protocol that is used to convey information as well as provide the ship's navigation ping [5]. The 13 bit message communicates the boat's location, heading, and speed to the AUVs. In this way every AUV will receive a navigation update with each navigation ping thereby improving the accuracy of the AUV position estimate [5].

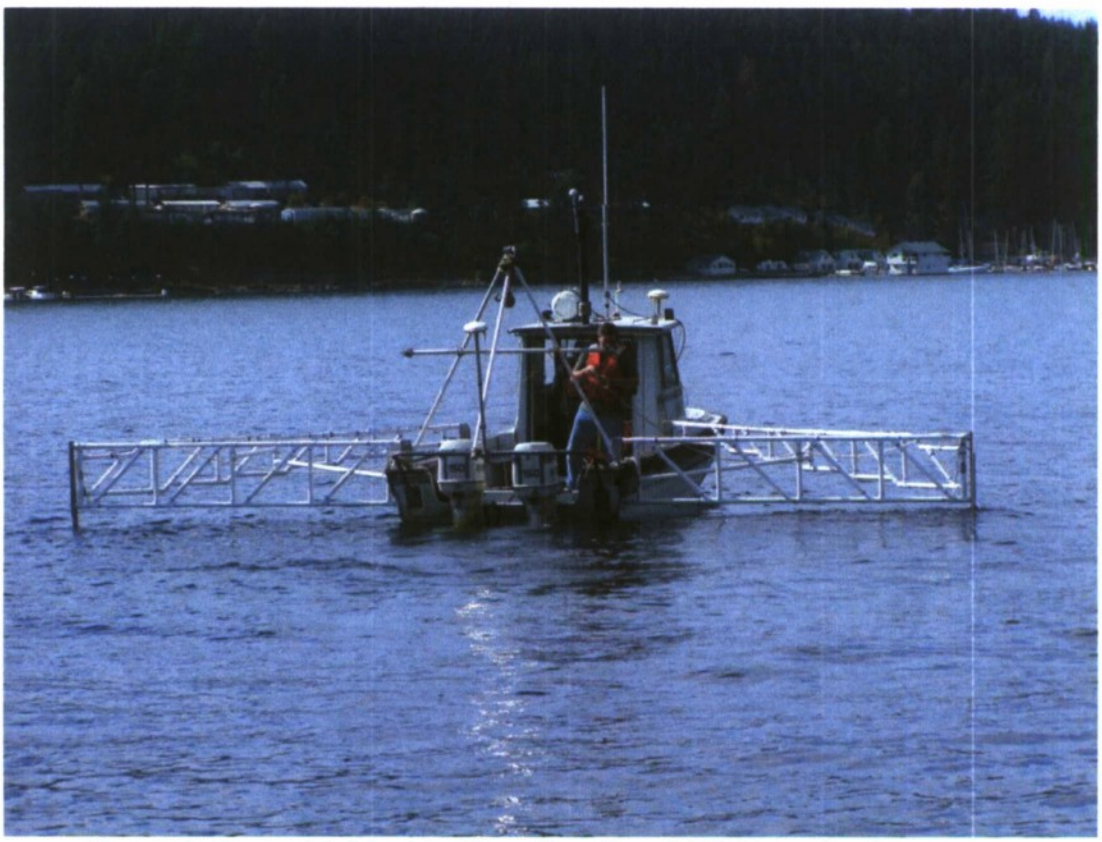

Figure 3. Boat with Moving Short Baseline (MSBL) navigation system.

The MSBL method or some variation thereof is the preferred method for implementing the magnetic signature assessment using multiple AUVs. The second best navigation method for doing these measurements would be to use the Sync-LBL. In this scenario, a temporary navigation transponder range is deployed, the transponder's location determined from surveys by surface boats, the magnetic measurements made by the AUVs, and then these transponders would be released and collected with the AUVs. The MSBL method is preferred because it does not require a temporary range to be installed before making the magnetic measurements. However, in either case the data would need to be recovered and processed. In post processing, further improvements in position estimates for each magnetic field measurement could be made using more computational intensive EKFs [6].

We have conducted a number of tests at the Acoustic Research Detachment located in Bayview, ID over the last year. These tests are characterized by the navigation method, the number of AUVs, and if the magnetic source was stationary or moving. We completed a number of tests on the stationary source using both active-LBL and sync-LBL navigation methods with single AUVs and multiple AUVs. These same tests performed on a stationary source were also done on a moving source attached to a boat. In addition, we have made magnetic measurements on a moving source using the MSBL navigation method with first a single AUV but most recently with multiple AUVs. The results of some of these tests will be reported in the next section.

In addition to the above work, we have also been investigating the logistical problems of using multiple AUVs as well as the methods by which we can automate and use vehicle intelligence to simplify these logistical problems. We have used computer simulations to investigate different scenarios for deploying, forming up, communicating, and retrieving AUVs as well as post processing all the data from multiple AUVs. While doing this work, we have developed an artificial intelligence called Language Centered Intelligence (LCI). We are investigating LCI to improve communications, system reliability, and cooperation between the multiple AUVs and operators. In one approach to reducing communication errors, we used LCI to develop a message anticipation module that uses natural language concepts to correct corrupted messages [7, 8]. We will continue to investigate different scenarios for implementing this mission including the logistics for handling all these AUVs and the communication between them and with human operators.

Because of concerns that our small AUV would not be able to survive a trip under a large ship or would have difficulty in navigating under the ship, we performed some hydrodynamic analysis on our AUV. The analysis modeled both the AUV and the attached magnetic sensor. Although more detailed results are reported in the next section, we found that the AUV would be able to survive the travel beneath the ship and should be able to have sufficient control to make accurate magnetic measurements. The results of this analysis were reported in [9].

RESULTS

Measurements of magnetic total field by one AUV executing multiple passes near a known fixed source in the deep-water facility are shown in Figure 4. The source consisted of four magnets bound together as a unit of total dipole strength of 448 Am^2, moored 9.4 m deep in the water. Part a of figure 4 shows the top view of the horizontal position of the AUV during several passes, and the total indicated magnetic field deviation from the terrestrial value measured by the magnetometer on the AUV. AUV position for these magnetic field measurements was determined by telemetry and sensor data acquired by the AUV. In part b of Figure 4, the deviation in measured total magnetic field is plotted as a line versus acquired time on the horizontal axis for an individual pass contained in part a of Figure 4. The predicted magnetic field computed using the AUV location as measured by an independent acoustic tracking system is plotted with + symbols. It is apparent that the AUV could measure the field of the known source to quite a high degree of precision. During the pass shown in Figure 4b, the magnitude of the total magnetic field caused by the known magnetic source was ~400 nT, a relatively small magnitude. The magnetometer-equipped AUV was able to measure this total field within an accuracy of <20nT [10], which includes the uncertainty in on-board position estimate. The precision of the measurement appears to be even better, <5nT.

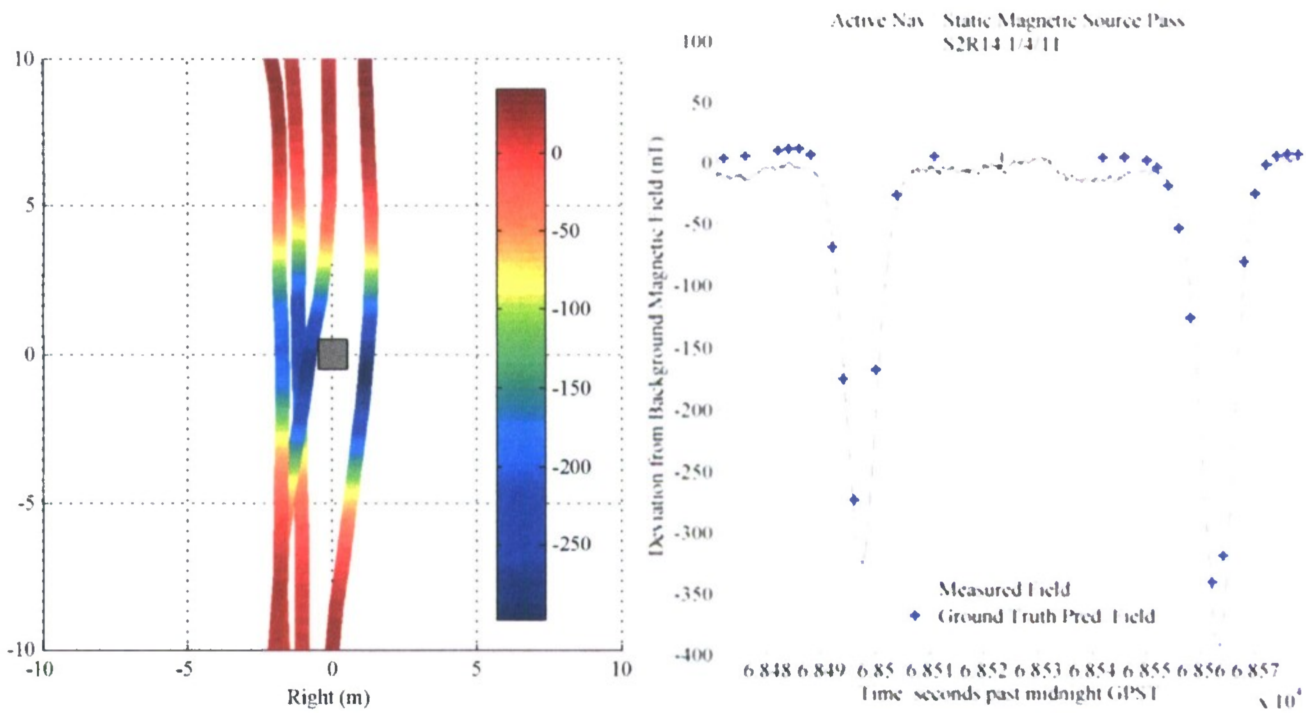

Figure 4. a)-left, Top-view of AUV position and measured total magnetic field, b)-right, total magnetic field near static magnetic source.

Experiments were performed using three AUVs to measure the magnetic field of the static known magnetic source of moment 448 Am^2. During these measurements, the AUVs navigated in synchronous mode using acoustic transponders mounted to the lake bottom. Synchronous mode allows for determination of range to a given transponder simultaneously by multiple vehicles. An example of this type of measurement is shown in Figure 5. In part a of Figure 5, a top view of the AUV position as determined from telemetry and sensor data acquired by the AUV is shown. The position-tracks are color-coded to indicate the measured total magnetic field. An enlarged inset shows the magnetic field measured by one of the AUVs. As can be seen, the AUV passed close enough to the source to measure a departure in total field relative to terrestrial of about 140 nT. In part b of Figure 5, the total magnetic field measured by the one of the AUVs is plotted against acquired time as a line. The pluses show the predicted magnetic field based upon the position of the AUV measured by an independent acoustic tracking system, and a model of the magnetic field produced by the known source. As can be seen, the measured total field is within 10 nT of what is predicted.

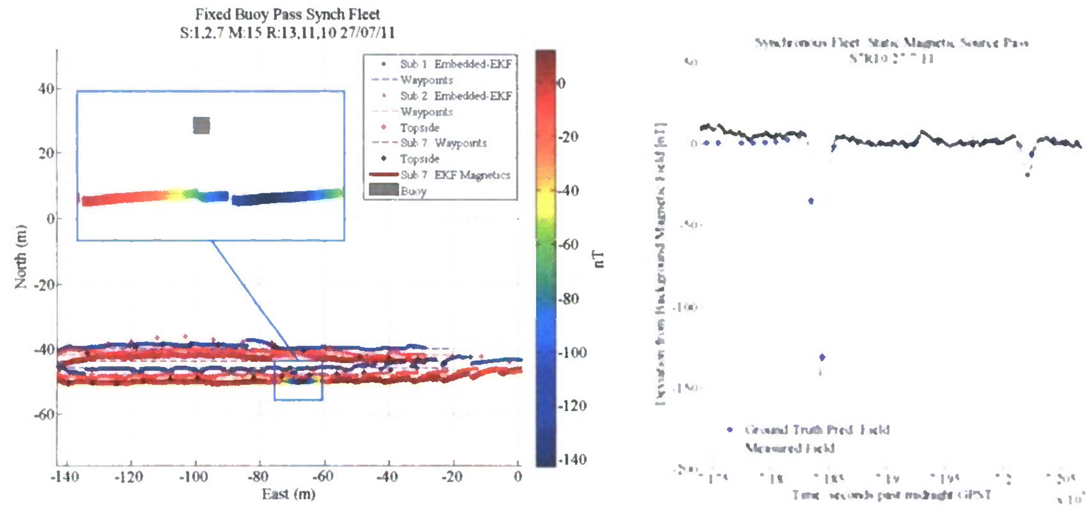

Figure 5. a)-left, Top-view of AUV position and measured total magnetic field, b)-right, total magnetic field near static magnetic source.

Experiments were performed using three AUVs to measure the magnetic field of known magnetic source attached to a moving surface vessel. The known magnetic source mounted to the surface vessel consisted of a single magnet of moment 135 Am^2. During these measurements, the AUVs navigated in active mode using acoustic transponders mounted to the lake bottom. In active mode, the range from an AUV to a fixed transponder is determined by measuring the time-of-flight for an acoustic pulse to travel from the AUV to the transponder and back to the AUV. In active mode, AUVs in a group determine the range to a given transponder in sequence, precluding application to large groups of AUVs. An example of this type of measurement is shown in Figure 6. In part a of Figure 6, a top view of the AUV position as determined from telemetry and sensor data acquired by the AUV is shown. The position-tracks are color-coded to indicate the measured total magnetic field. An enlarged inset shows the magnetic field measured by one of the AUVs. The measurements of magnetic field measured by the magnetometer on the AUV are indicated with solid lines, and a prediction of the magnetic field based upon the location of the AUV measured by an independent acoustic tracking system are indicated with +'s. Transmissions of acoustic pulses required for the independent tracking system caused interference that is observed on the magnetic field measured by the magnetometer on the AUV. This interference would not be present in an AUV magnetic signature measurement system, because independent acoustic tracking would not be required. As can be seen, the AUV passed close enough to the source to measure a departure in total field relative to terrestrial value of about 140 nT. In part b of Figure 6, the total magnetic field measured by the one of the AUVs is plotted against acquired time as a line. The pluses show the predicted magnetic field based upon the position of the AUV measured by an independent acoustic tracking system, and a model of the magnetic field produced by the known source. As can be seen, the measured total field was within 10 nT of what was predicted.

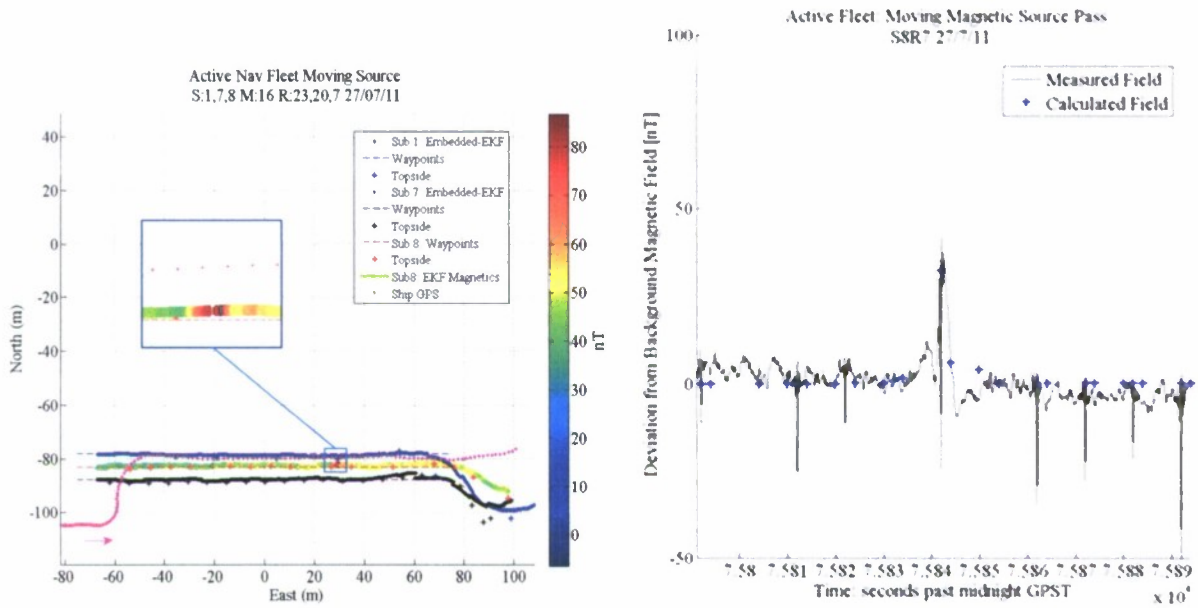

Figure 6. a)-left, Top-view of AUV position and measured total magnetic field, b)-right, total magnetic field near encounter with moving surface vessel.

Experiments were also performed using AUVs to measure the magnetic signature of a moving surface vessel in a navigation mode intended for application. In this mode, the AUVs navigate using synchronously using acoustic transponders attached to the surface vessel, instead of using transponders fixed to the bottom. In the experiments, the surface vessel navigated a straight course in the deepwater facility. Simultaneously, an AUV was launched. The AUV navigated a course that allowed it to pass under the moving surface vessel in the opposite direction. For navigation, the AUV received `3-bit acoustic messages from the transponders located on the surface vessel. The AUVs could determine the range to the surface vessel by measuring the time of arrival of the message, and the content of the message contained information about the speed, heading and inertial location of the surface vessel. The results of an experiment are shown in Figure 7. In this particular example, the surface vessel was not equipped with a known magnetic source, and the magnetic signature measured by the magnetometer on the AUV was that of the surface vessel itself. In part a of Figure 7 is shown the top-view of the position track taken by the AUV as determined by information acquired by the AUV during the experiment. The position tracks are color-coded to indicate the departure in total magnetic field from the terrestrial value measured by the AUV. The inset in part a of Figure 7 shows the position of the AUV as it passed nearest to the moving surface vessel. A large jump occurred just before the AUV passed the surface vessel. This behavior was caused by the fact that the AUV navigation algorithm was able to resolve the separation of the acoustic transponders attached to the surface vessel, and the position estimate by the AUV became more accurate. It is apparent that the AUV passed within 5 m of the intended path of the surface vessel. In part b of Figure 7 is the indicated total magnetic field measured by the AUV as it passed the ship. As can be seen, the magnetometer on the AUV was able to detect the presence of a signature caused by the moving surface vessel, which at the distance of ~5m was approximately 60 nT.

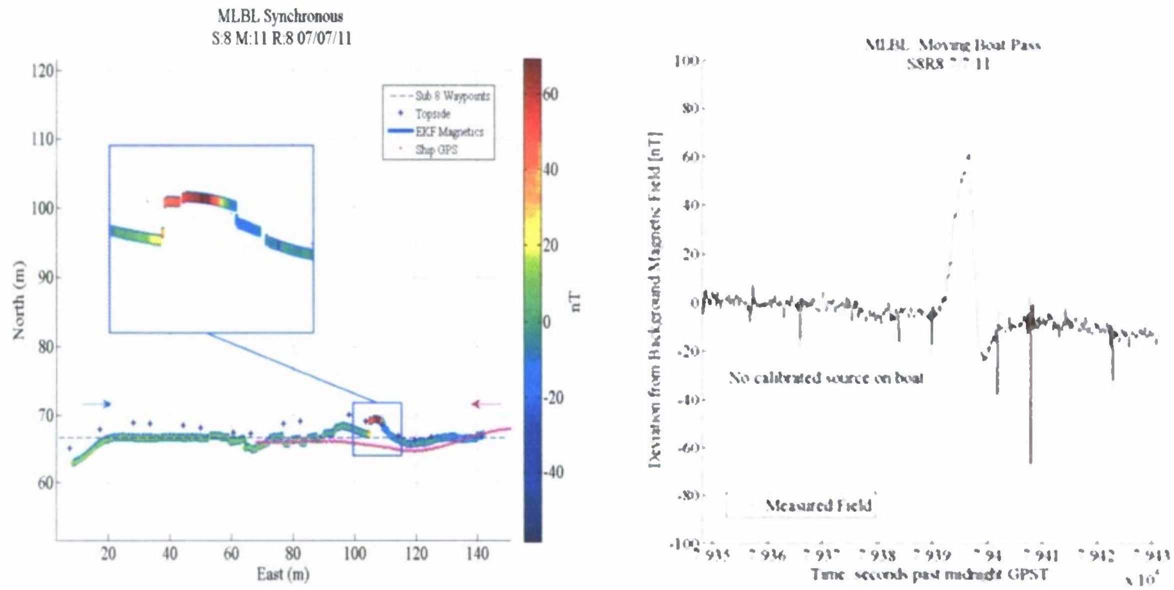

Figure 7. a)-left, Top-view of AUV position and measured total magnetic field, b)-right, total magnetic field near encounter with moving surface vessel.

By assuming potential flow of invisid fluid with infinite extent and no boundary layer separation, the force and torque experienced by an AUV traversing under a moving ship along a prescribed horizontal straight-line are studied by a panel method. An example using typical conditions for acquiring the magnetic signature of a surface ship is given in Figure 8. The figure illustrates how the translating flow field of the ship imparts hydrodynamic loads on the AUV and the magnitude of these loads. At one beam depth and in deep water (i.e., the flow field surround the AUV is not affected by the sea floor), the hydrodynamic loads under the assumptions made are small. Boundary layer separation will result in greater loads. This effect of is being investigated at present time. However, judging from the small hydrodynamic loads and with the expectation that boundary layer separation should not materially alter the results obtained so far, we conclude that the hydrodynamic loads should be manageable from the perspective of AUV survivability.

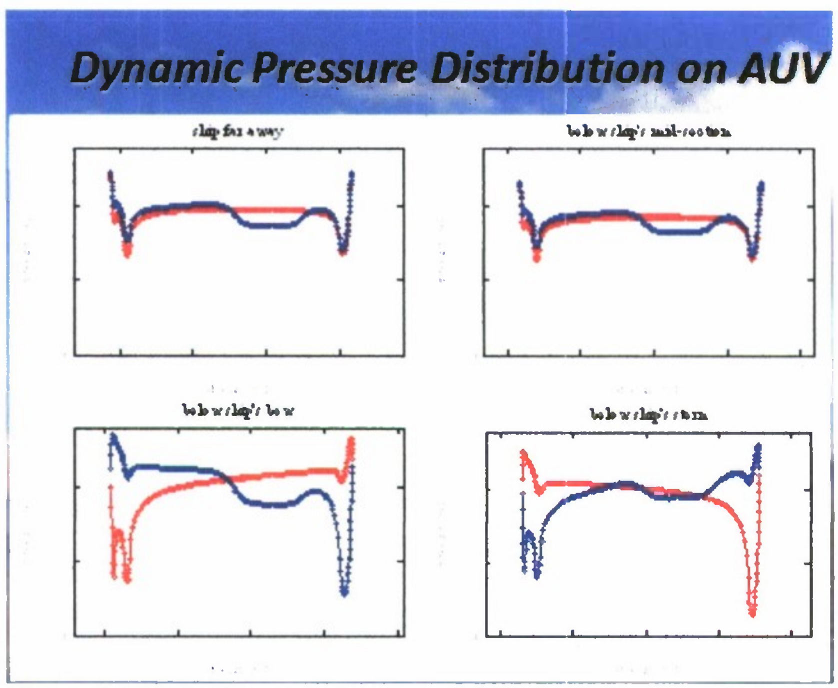

Figure 8. Hydrodynamic loads on AUV during pass under surface vessel.

IMPACT/APPLICATIONS

Currently, ships and submarines are degaussed in a naval shipyard. While onboard systems allow the vessels to compensate for inevitable ship magnetic field changes acquired as a result of deployed transoceanic voyages, the missing piece is an accurate real-time assessment of those changes at their destinations. The portable assessment system being developed in this project would allow the magnetic signature of a ship to be determined and possibly degaussed anywhere in the world.

RELATED PROJECTS

This task leverages three previous ONR-funded projects, Decentralized Control of Multiple Autonomous Underwater Vehicles (ONR Grant N000140310634), Decentralized Control of Multiple Autonomous Crawlers and Swimmers (ONR Grant N000140310848), Communication and Control for Fleets of Autonomous Underwater Vehicles (ONR Grant N000140410506). In addition, small AUVs fabricated under another related project, Fabrication of a Fleet of Mini-AUVs (ONR Grant N000140410803), are being tested at Bayview under this project. Another related project is the Cooperative Autonomous Underwater Vehicles Used to Search Large Ocean Areas for Mines (ONR Grant N00014-08-1-0276).

REFERENCES

1. J. Pentzer*, B. Armstrong*, D. Odell*, T. Bean, J. Canning, M. Anderson, D. Edwards, "On-the-Fly Measurement of Surface Ship Acoustic and Magnetic Signature Using Multiple AUVs", *Proceedings of MSS Battlespace Acoustic and Seismic Sensing, Magnetic & Electric Field Sensorw (BAMS) Symposium*, 2009.
2. B. Armstrong*, J. Pentzer*, D. Odell, T. Bean, J. Canning, D. Pugsley, J. Frenzel Michael Anderson, D. Edwards, "Field Measurement of Surface Ship Magnetic Signature Using Multiple AUVs", *Proceedings MTS/IEEE Oceans 09*, 2009.
3. B. Armstrong, E. Wolbrecht, D. Edwards, "AUV Navigation in the Presence of a Magnetic Disturbance with an Extended Kalman Filter", Sydney IEEE Oceans 2010.
4. J. Pentzer*, B. Armstrong*, T. Bean, M. Anderson, D. Edwards, N.V. Schmehl, "Preventing Extended Kalman Filter Instabilities During Two Transponder Long Baseline Navigation with Real Time Fuzzy Logic Parameter Adjustment", *Proceedings of IEEE Oceans* 2009, 2009.
5. B. Crosbie*, M Anderson*, E. Wolbrecht, J. Canning, D. Edwards, "Synchronous Navigation of AUVs Using WHOI Micro-Modem 13-bit Communications", *Seattle IEEE Oceans 2010.*
6. J. Pentzer, B. Armstrong, J. Canning, T. Bean, D. Odell, D. Edwards, M. Anderson, E. Wolbrecht, J. Frenzel, "Spatial Sampling of Magnetic Field Using Collaborating Autonomous Underwater Vehicles", *Proceedings of MSS Battlespace Acoustic and Seismic Sensing, Magnetic & Electric Field Sensorw (BAMS) Symposium*, 2010.
7. N. John Hallin, J. Horn, H. Taheri, M. O'Rourke, D. Edwards, "Message Anticipation Applied to Collaborating Unmanned Underwater Vehicles", *Proceedings MTS/IEEE Oceans 11*, 2011.
8. Hallin, N., H. Taheri, J. Horn, M. O'Rourke, D. Edwards, "Architecture and Applications of Language-Centered Intelligence for Unmanned Underwater Vehicles," *Proceedings of 2011 IEEE International Conference on Systems, Man, and Cybernetics*, Anchorage, Alaska, October 9-12, 2011.
9. J. C. P. Liou, "AUV Hydrodynamics for Survivability and Controllability", *Proceedings MTS/IEEE Oceans 11*, 2011.
10. C. Walker, B. Armstrong, T. Bean, J. Canning, E. Wolbrecht, M. Anderson, D. Edwards, "Calibration and Localization of AUV-acquired Magnetic Survey Data", *Proceedings MTS/IEEE Oceans 11*, 2011.

PUBLICATIONS

1. J. Pentzer*, B. Armstrong*, D. Odell*, T. Bean, J. Canning, M. Anderson, D. Edwards, "On-the-Fly Measurement of Surface Ship Acoustic and Magnetic Signature Using Multiple AUVs", *Proceedings of MSS Battlespace Acoustic and Seismic Sensing, Magnetic & Electric Field Sensorw (BAMS) Symposium*, 2009. [published]
2. B. Armstrong*, J. Pentzer*, D. Odell, T. Bean, J. Canning, D. Pugsley, J. Frenzel Michael Anderson, D. Edwards, "Field Measurement of Surface Ship Magnetic Signature Using Multiple AUVs", *Proceedings MTS/IEEE Oceans 09*, 2009. [published]
3. J. Pentzer*, B. Armstrong*, T. Bean, M. Anderson, D. Edwards, N.V. Schmehl, "Preventing Extended Kalman Filter Instabilities During Two Transponder Long Baseline Navigation with Real Time Fuzzy Logic Parameter Adjustment", *Proceedings of IEEE Oceans* 2009, 2009. [published]
4. B. Armstrong, E. Wolbrecht, D. Edwards, "AUV Navigation in the Presence of a Magnetic Disturbance with an Extended Kalman Filter", Sydney IEEE Oceans 2010. [published]
5. B. Crosbie*, M Anderson*, E. Wolbrecht, J. Canning, D. Edwards, "Synchronous Navigation of AUVs Using WHOI Micro-Modem 13-bit Communications", *Seattle IEEE Oceans 2010*. [published]
6. J. Pentzer, B. Armstrong, J. Canning, T. Bean, D. Odell, D. Edwards, M. Anderson, E. Wolbrecht, J. Frenzel, "Spatial Sampling of Magnetic Field Using Collaborating Autonomous Underwater Vehicles", *Proceedings of MSS Battlespace Acoustic and Seismic Sensing, Magnetic & Electric Field Sensorw (BAMS) Symposium*, 2010. [published]
7. D. Odell, J. Pentzer*, J. Canning*, D. Edwards*, "A Versatile Tracking System for AUV Testing", Sydney IEEE Oceans 2010. [published]
8. B. Morton, T. Soule, A. Kanago, J. Frenzel, D. Edwards, "Ordering Autonomous Underwater Vehicle Inspection Locations with a Genetic Algorithm", Seattle IEEE Oceans 2010. [published]
9. A. Folk, B. Armstrong, E. Wolbrecht, H. Grip, M. Anderson, D. Edwards, "Autonomous Underwater Vehicle Navigation using Moving Baseline on a Target Ship", Seattle IEEE Oceans 2010. [published]
10. J. Pentzer, B. Crosbie, T. Bean, J. Canning, J. Frenzel, M. Anderson, D. Edwards, "Measurement of Magnetic Field using Collaborative AUVs", Sydney, IEEE Oceans 2010. [published]
11. N. John Hallin, J. Horn, H. Taheri, M. O'Rourke, D. Edwards, "Message Anticipation Applied to Collaborating Unmanned Underwater Vehicles", *Proceedings MTS/IEEE Oceans 11*, 2011. [published]
12. J. C. P. Liou, "AUV Hydrodynamics for Survivability and Controllability", *Proceedings MTS/IEEE Oceans 11*, 2011. [published]
13. Roos, K., F. De La Garza, J. Frenzel, D. Edwards, "Low-cost Pulse-per-Second (PPS) Signal Generator for Autonomous Underwater Vehicles," *Proceedings of the 17th International Symposium on Unmanned Untethered Submersible Technology* (UUST'11), Portsmouth, New Hampshire, August 21-24, 2011. [published]
14. Hallin, N., H. Taheri, J. Horn, M. O'Rourke, D. Edwards, "Architecture and Applications of Language-Centered Intelligence for Unmanned Underwater Vehicles," *Proceedings of 2011 IEEE International Conference on Systems, Man, and Cybernetics*, Anchorage, Alaska, October 9-12, 2011. [published]
15. C. Walker, B. Armstrong, T. Bean, J. Canning, E. Wolbrecht, M. Anderson, D. Edwards, "Calibration and Localization of AUV-acquired Magnetic Survey Data", *Proceedings MTS/IEEE Oceans 11*, 2011. . [published]